Engineering, Operations & Technology
Boeing Research & Technology

Non-Cr paint systems on commercial aircraft – current status and future direction

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Overview
Boeing Commercial Airplanes

Cr^{6+} Overview

Historic & Current use of Cr^{6+}

Chromate use and alternatives

Strategy for Sunset Date

Near term systems and qualifications

Gaps and long term developments

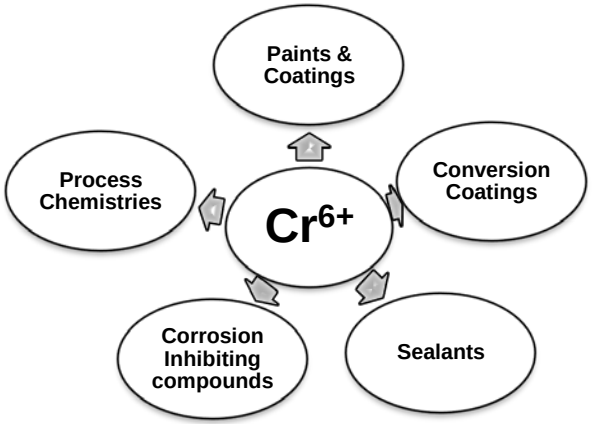
Cr^{6+} Overview

Cr^{6+} is a known carcinogen and an excellent corrosion inhibitor

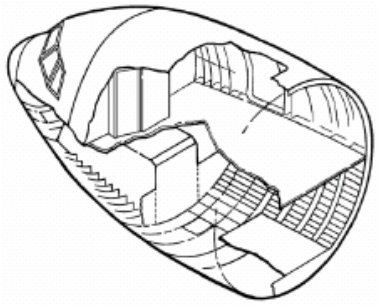
Gold Standard of Corrosion Inhibitors

Carcinogenic

- REACH Sunset Date 2017-2019
- Hazardous Waste
- OSHA Permissible Exposure Limit 5 µg/m^3



Historic & Current use of Cr^{6+}
Boeing Commercial Airplanes



Cr^{6+} containing materials have been used on all metal parts, including aluminum, titanium, and stainless steel alloys.

Over 75% of the plane is coated with chromated materials.

Successful Cr^{6+} reductions via:

- Substrates and Design changes (composite materials, titanium, guidelines, etc.)
- Alternative materials (products and processes)

Item	Division	Sub-division	Surface of part	Location on airplane	Finish requirement
Bare plate and sheet, extruded shapes, extruded bar drawn or rolled bar, forged block, forgings and castings **FN 3**				Fuselage lower lobe **FN 1**	Anodize + two coats BMS 10–11 Type I primer
				Fuselage upper lobe	Anodize + BMS 10–11 Type I primer
				Nonaero-dynamic exterior	Anodize + BMS 10–11 Type I primer
				Exterior Aerodynamic	Anodize + BMS 10–79 Type III primer + BMS 10–60 Type II white enamel or BMS10-126 Type II
				Landing gear	Anodize + BMS 10–79 Type III primer + BMS 10–60 Type II gray enamel
	Attached to CFRP **FN 8** **FN 3**		Within 4 in of CFRP **FN 54**	General except as noted below	Anodize + two coats BMS 10–11 Type I primer
				Located in integral fuel tank	Anodize + two coats BMS 10–20 Type II primer
				Exterior Aerodynamic, Wing and empennage trailing edge coves	Anodize + two coats BMS 10–79 Type III primer

Corrosion Potential Table

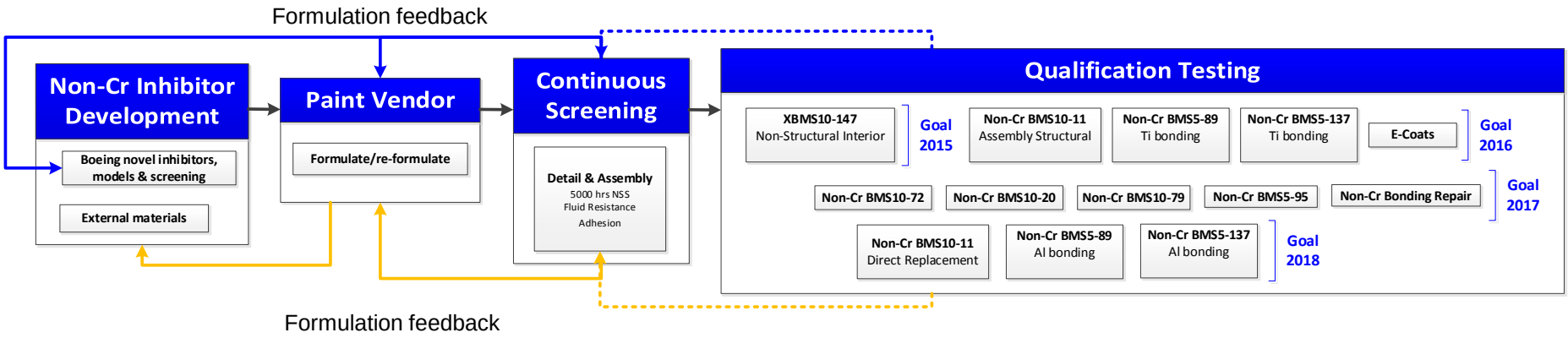
Group	Metal or alloy
I	Magnesium and its alloys
II	Aluminum, zinc, and their alloys. Cadmium–titanium, cadmium or zinc-nickel plating
III	Steels (except CRES), Iron, lead, tin, and their alloys. Tin plating.
IV	CFRP, titanium and titanium alloys, CRES, bronze (aluminum-bronze or aluminum-nickel-bronze), nickel and nickel alloys, chromium (plating), copper, brass, copper-nickel, copper-beryllium, molybdenum, cobalt alloys, tungsten, carbon, silver, and gold

Chromate Alternative Successes and Targets

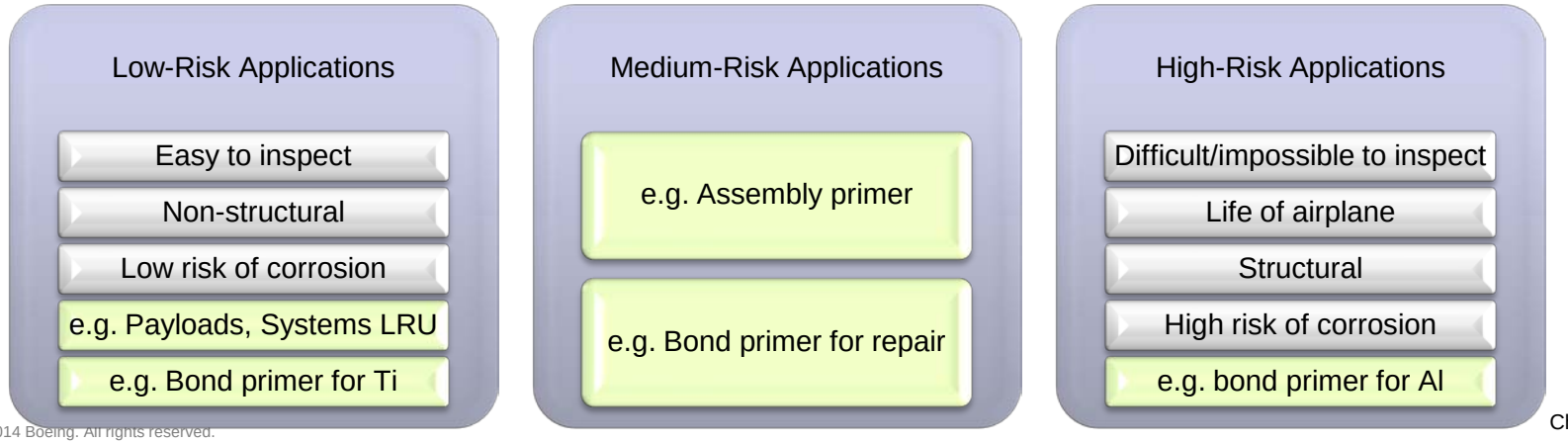
Chromated material/process	Alternatives
Chromic acid anodize	Boric sulfuric acid anodize (BSAA), Accelerated sulfuric acid anodize (ASAA)
Deoxidizers	Ferric/nitric deoxidizers
Paint strippers	Mechanical, benzyl alcohol based. In work: laser & atmospheric plasma
Composite primers	BMS10-103
Exterior primer (BMS10-72, MIL-PRF-23377)	BMS10-72 NC In work: searching for Cr^{6+} equivalency
Non-structural interior primer (BMS10-11 Ty I lite)	In work: XBMS10-147
Structural interior primer (BMS10-11 Ty I, MIL-PRF-85582, MIL-PRF-23377)	In work
Bond primer (BMS5-89, BMS5-137)	In work
Assembly level primer	In work
BMS10-20 (SAE-AMS-C-27725)	In work
BMS10-79	In work
BMS5-95	In work

Strategy for Sunset Date
Non-Cr for BMS10-11, BMS10-20, BMS10-72/BMS10-79, BMS5-89

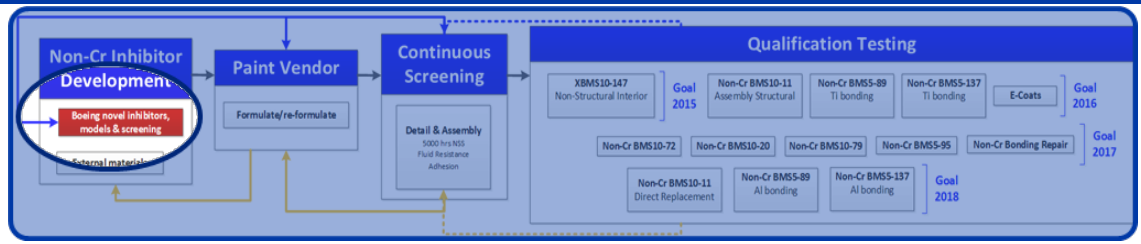
Multidimensional approach:

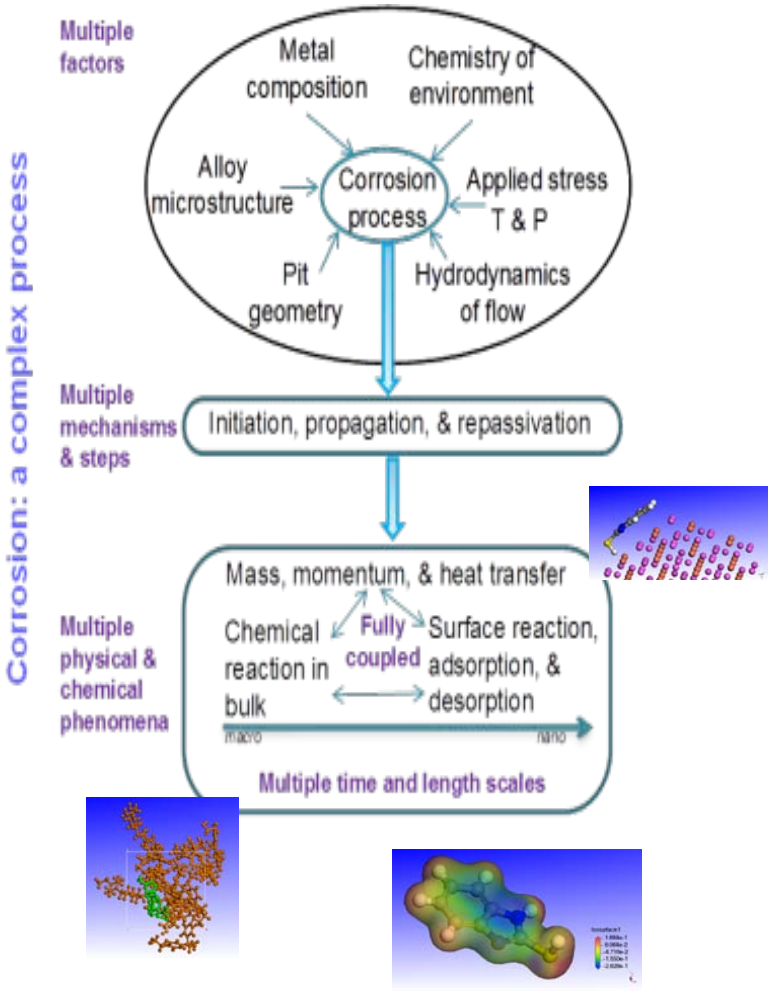


Test top candidates to the spec requirements, match product performance to application.



Corrosion Protection
System Development



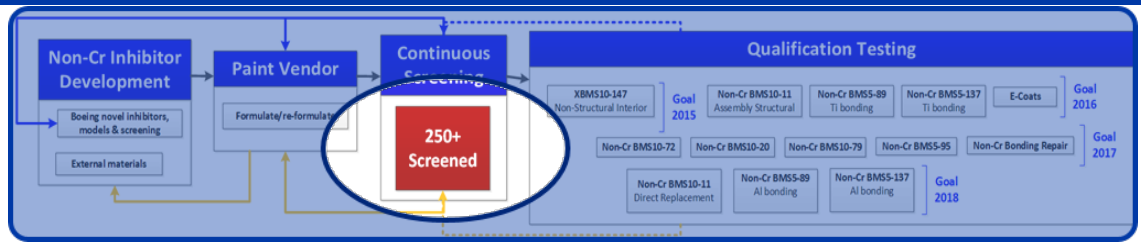


Materials development
- CSIRO, Boeing, Suppliers, universities
- Inhibitor species
- Polymer resins
- Formulation nuances

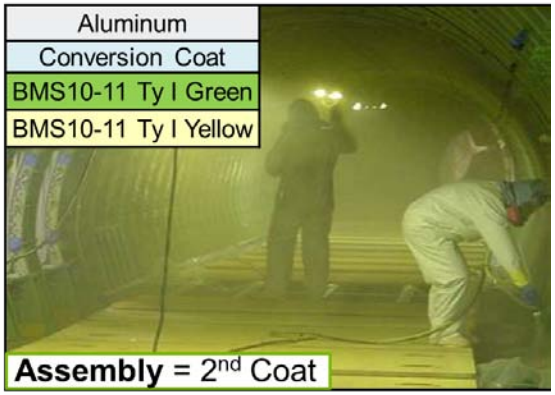
Testing/evaluation
- Boeing, universities, CSIRO
- Accelerated exposure protocols
- Advanced evaluation techniques

Modeling tools
- Boeing, CSIRO, universities
- Inhibitor mechanisms
- Transport processes
- Service performance prediction

Continuous Screening
Overview



Materials Process Example:



Test panel stack-ups:

Detail Primer:

7075-T6 Bare Al		
Alodine 600	BSAA Unsealed	BMS10-128
BMS10-11 Ty I Green or Candidate		

Assembly Primer:

7075-T6 Bare Al		
Alodine 600	BSAA Unsealed	BMS10-128
BMS10-11 Ty I Green		
BMS10-11 I Yellow or Candidate		

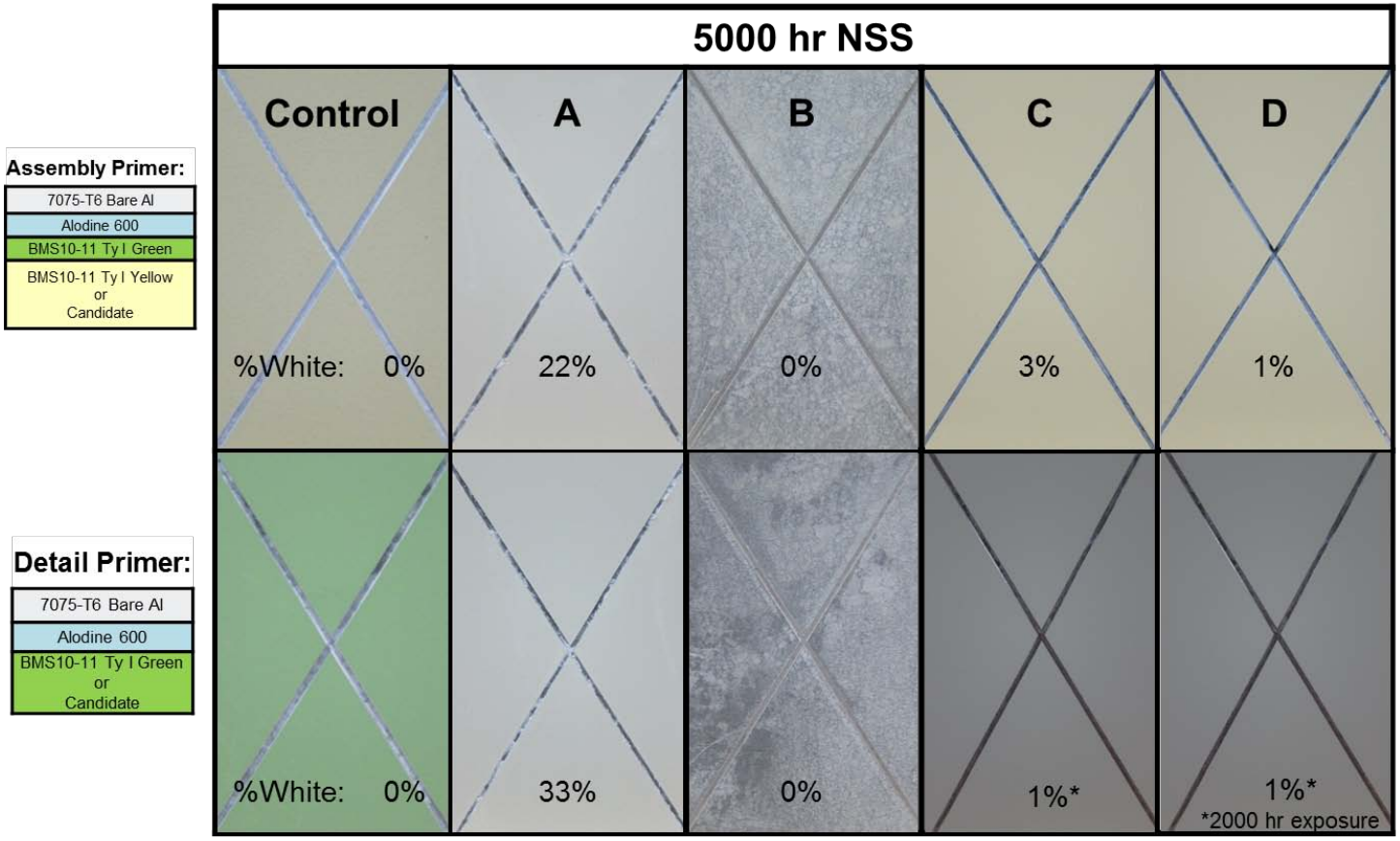
Screening Tests:

- Dry/Wet Adhesion. BSS7225, ASTM D 714.
- 30 days 120F condensing humidity. BSS7225, ASTM D 714
- 30 day hydraulic fluid soak. BSS7263, ASTM D 714
- 5000 hours in Neutral Salt Spray chamber. BSS7249, ASTM D 714

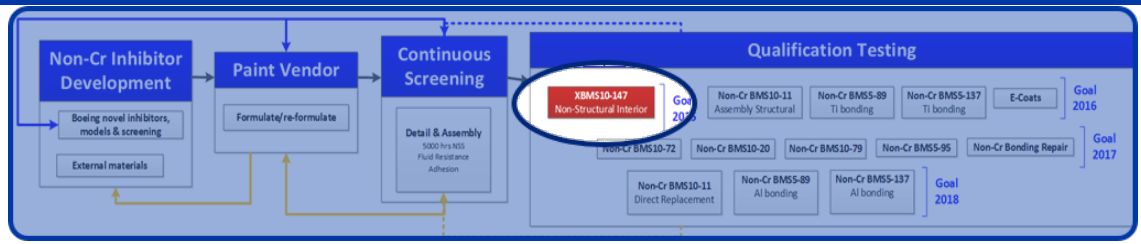
Candidates that look good in screening, move to production batch testing

Continuous Screening
Medium/High risk zones

Four candidates are moving to production batch testing to BMS10-11 Ty I, BMS10-20, BMS10-72, & BMS10-79



XBMS10-147
Low-corrosion risk zones



Technical Requirements

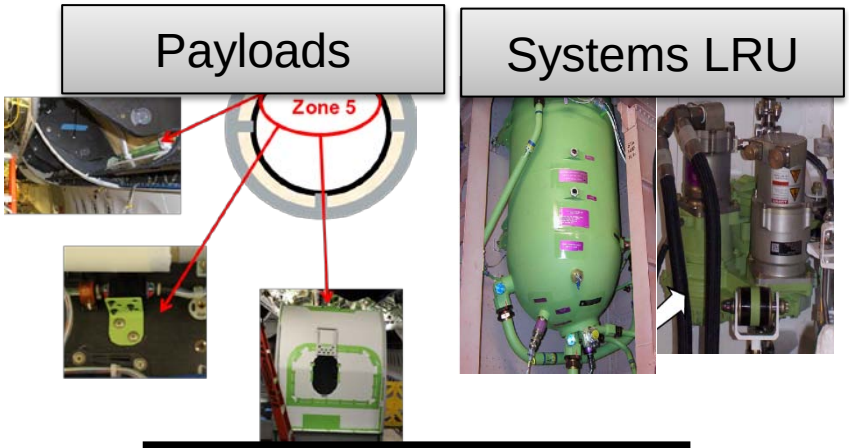
- Corrosion resistance criteria based on MIL-PRF-23377, but with a wider scribe.
  - Neutral Salt Spray (NSS) for 2000 hrs, no pitting & minimal oxides within the scribe.
- Compatibility requirement testing based on application

Opportunities

- Interior payloads primer for non-structural parts (brackets, clips, stow-bin rails, etc…) – All models
- Systems Line Replaceable Units (LRU), such as ducts, valves, pumps, etc…) – 777X

Status:

- 7 candidates tested, top candidate reformulated for improved adhesion (blisters)
  - Reformulation successful, candidate currently in qual testing

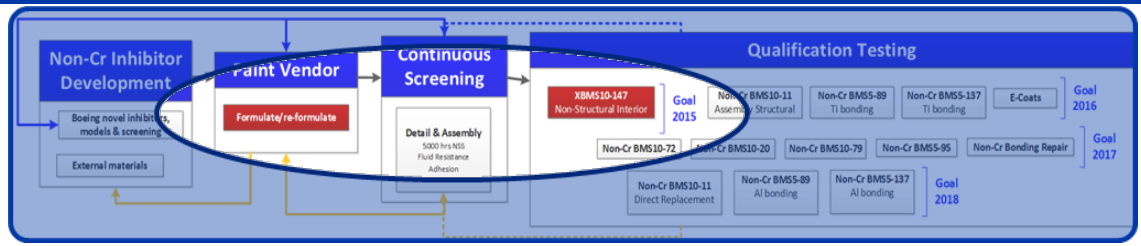


Key Tests	Application: Payloads, Systems, Both	8	7	6	5	4	3	2	1
Spray Properties	Both	TBD	PASS	PASS	MARGINAL	PASS	PASS	FAIL	PASS
Drying Properties	Both	PASS SCREENING	PASS	FAIL	PASS	PASS	PASS	PASS	PASS
Color	Payloads	PASS SCREENING	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Gloss	Payloads	TBD	PASS	FAIL	FAIL	PASS	FAIL	FAIL	PASS
Adhesion	Both	PASS SCREENING	FAIL BLISTERS	PASS	PASS	FAIL	FAIL	MARGINAL	FAIL
Humidity	Both	PASS SCREENING	FAIL BLISTERS	PASS	PASS	FAIL	FAIL	PASS	FAIL
Neutral Salt Fog 2000 hrs	Both	TBD	PASS EXCELENT!!!	PASS ACCEPTABLE	FAIL	PASS GOOD	FAIL	FAIL	FAIL
Fluid Resistance	Both	PASS SCREENING	PASS	FAIL	PASS	PASS	FAIL	PASS	PASS
Rivets & Fasteners Adhesion	Both	PASS SCREENING	FAIL BLISTERS	PASS	--	FAIL	--	FAIL	FAIL

Compatibility requirements by application:

Materials	Payloads Applications	Both	Systems Applications
Substrates		2000 series bare	Al Castings
		7000 series bare	Ti 6Al-4V
		6000 series bare	CRES
Substrate Prep	BSAA Unsealed	BSAA Sealed	Grit Blast
	CAA Unsealed	CAA Sealed	Cd plating, Cr6+
	Sol-Gel	Alodine 600	Zn-Ni plating, Cr6+
		Alodine 1200	Zn-Ni plating, Cr3+
			TCP (Navy Cr3+)
Fluids		BMS3-11	BMS3-32 Ty II
		Fuel	
		Water	
		solvents (MEK)	
Primers	BMS10-11 Tyl Gr A	PR-1200 RTV	
	BMS10-11 Tyl Gr B		
	BMS10-11 Tyl Gr E		
	BMS10-83 Ty IV		
Topcoats	BMS10-83 Ty II	BMS10-60 TY I	BAC5710 Ty 41
	BMS10-83 Ty VII	BMS10-11 Ty II	
Sealants	BMS5-142	BMS5-95	
		BMS5-45	
Adhesives		BAC5010 Ty 60	
		BAC5010 Ty 70	
		BAC5010 Ty 89	

XBMS10-147
Top Candidate



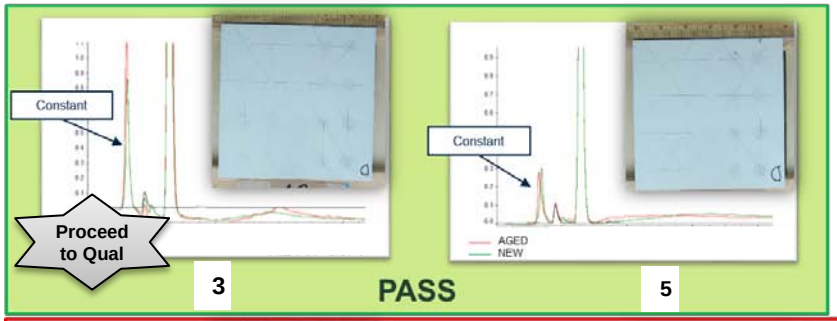
Curing Solution Reformulation
- 5 candidates screened
- Tested Fresh vs Aged 4 months @ 120F
- Chemistry vs mechanical properties

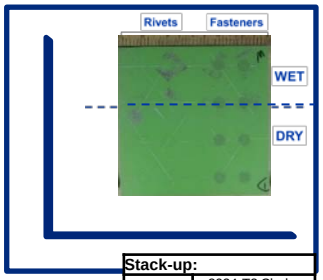
Liquid Component Testing
- HPLC
- FTIR
- GPC
- LCMS

Cured Film Testing
- Rivets/Fasteners Adhesion
- Wet/Dry Adhesion
- 120F Condensing Humidity
- SEM/EDS

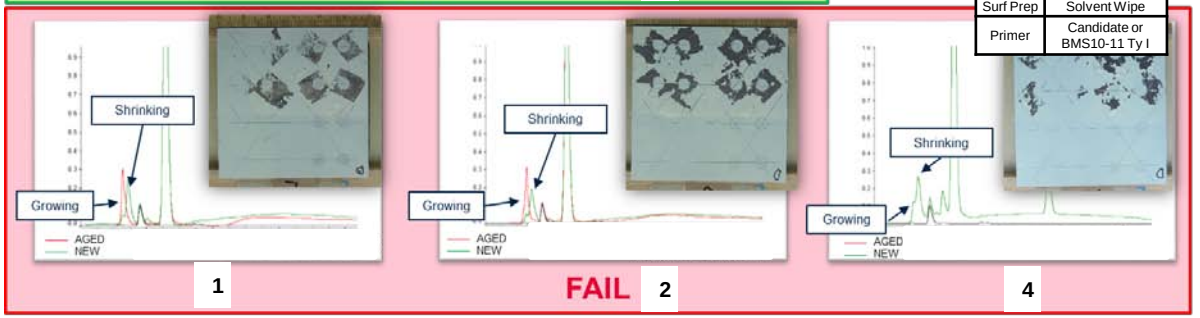
Top re-formulation proceeding to qual
- 1st production Batch sprayed Sept 2014

Curing solution chemistry aging vs cured film adhesion properties





Stack-up:	
Substrate	2024-T3 Clad + Rivets & Fasteners
Surf Prep	Solvent Wipe
Primer	Candidate or BMS10-11 Ty I

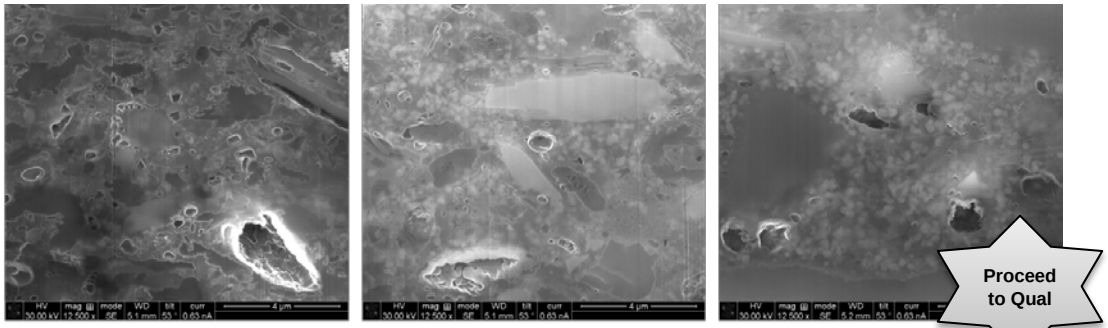


Curing solution components per reformulation.

candidate	initial	1	2	3		4		5	
part	B	B	B	B	C	B	C	B	C
Components									
Adh. Rivets & Fasteners	FAIL	FAIL	FAIL	PASS		FAIL		PASS	

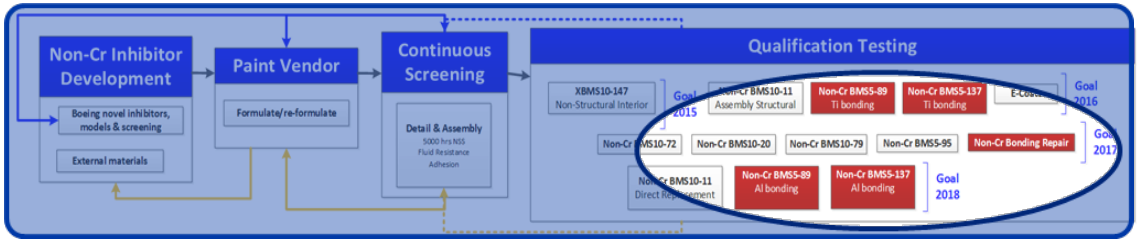
Proceed to Qual

SEM – focused ion beam paint cross-section at 12,500x mag



initial 4 3

Adhesive Bond Primer
High/Medium/Low risk zones



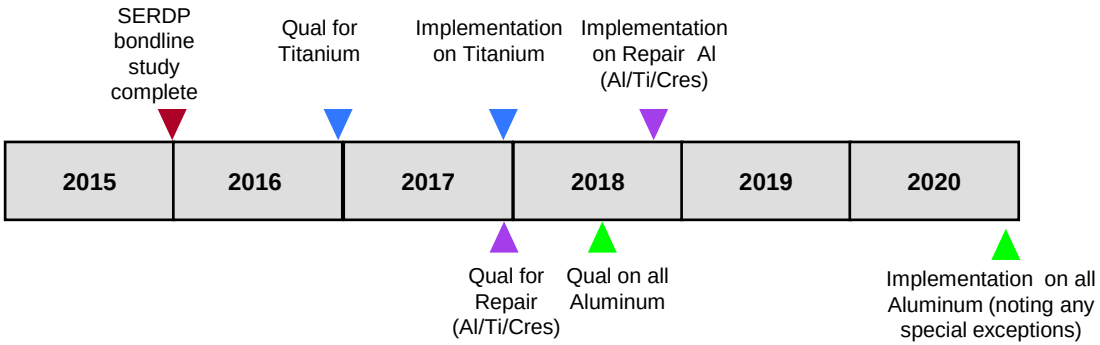
Overview

- Two candidates selected based on performance over on titanium/sol-gel and aluminum/PAA substrates
- The desired goal is to find a primer that can do both aluminum and titanium bonding at both 250F and 350F processing temperatures

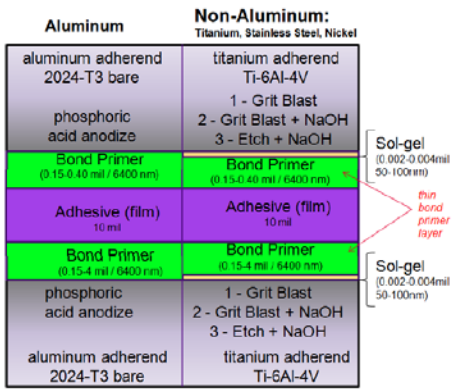
Key Tests

- Wide Area Lap Shear - *BSS7202 Type III*
- Metal to Metal Peel - *BSS7206 Class 1, ASTM D 1781*
- Salt Spray – *Scribed panels, ASTM B117*
- Wedge Crack – *BSS7448 ASTM D 3762*

Qual & Implementation Goals:

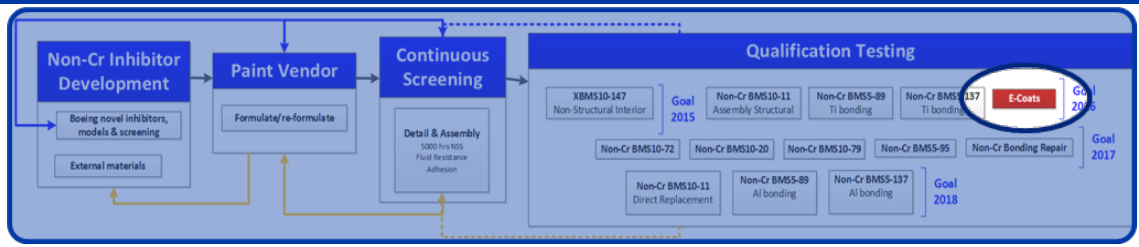


Bond Primers are Applied on Variety of Surface Treatments and Alloys



- **Boeing Specifications:**
  - BMS 5-89
  - MMS350, Ty III
  - MMS307, Type II
  - HMS 16-1111, Ty 1
  - HMS 16-1278, Ty 1
  - BMS 5-137
  - DMS 2002, Ty 3 & 4
  - DMS 2169, Ty 1(A)
  - SCGMS56033, Class 2

Electrocoat (e-coat)
Low corrosion-risk zones



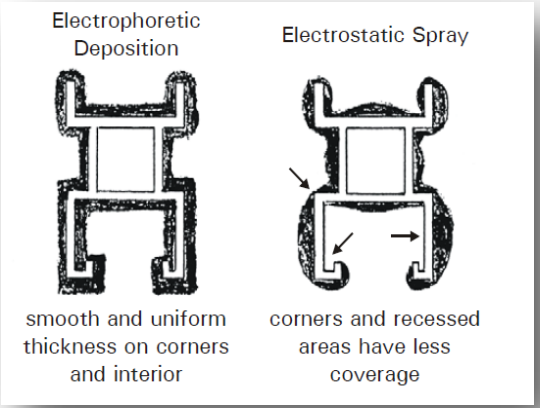
Process:

- Automated, low waste process which provides uniform paint film thickness.

Overview:

- Potential use for complex geometries, such as tubes in low corrosion-risk zones
- One candidate has passed screening tests, with varying degrees of corrosion protection depending on metal alloy.

Plans to acquire a Pilot Coater in 2015



Gaps & Long Term Developments

Gaps:

- In-service testing and long term exposure. Will not be accepted until proven in service.
  - 50-100k cycles per commercial aircraft
  - Lifecycle of 20+ years
  - Corrosion observed after 8-10 years in-service for Cr
- Risks associated with unknown failure of primary structure
  - Flight and safety critical components
    - Interaction between corrosion effects and fatigue crack initiation is unknown
- Reliable inspection methods
  - Implement nonchromate systems with increased inspection
  - Understand relationship between corrosion morphology and fatigue initiation/propagation
- Risk based implementation increases manufacturing complexity
  - Ensuring the correct coating system on the correct application

Current Authorization Needs: List 3 and 4 Chromates

Identification			Authorisation Dates		REACH Authorization Needed		
List	Substance	CAS	Last Application	Sunset	BCA	BDS	Combined
3	Ammonium Dichromate	7789-09-5	3/21/2016	9/21/2017	NO	NO	NO
3	Chrome Trioxide	1333-82-0			YES	YES	YES
3	Chromic Acid, hydrated forms	7738-94-5 & 13530-68-2			YES	YES	YES
3	Potassium Chromate	7789-00-6			NO	NO	NO
3	Potassium Dichromate	7778-50-9			YES	YES	YES
3	Sodium Chromate	7775-11-3			YES	YES	YES
3	Sodium Dichromate	7789-12-0 & 10588-01-9			YES	YES	YES
4	Dichromium tris (chromate)	24613-89-6	7/22/2017	1/22/2019	NO	NO	NO
4	Pentazinc Chromate Oxtahydroxide	49663-84-5			NO	NO	NO
4	Potassium hydroxyoctaoxodizincatedichromate	11103-86-9			YES	YES	YES
4	Strontium Chromate	7789-06-2			YES	YES	YES

BCA Chemical Risk Management is interested in discussing partnering opportunities in the chromate use application process